NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

**TRANSITION TO
ASYNCHRONOUS TRANSFER MODE (ATM)
AN IMPLEMENTATION MODEL FOR NPS SOFTWARE
METRICS LAB**

by

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March 1999

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TRANSITION TO ASYNCHRONOUS TRANSFER MODE (ATM) AN IMPLEMENTATION MODEL FOR NPS SOFTWARE METRICS LAB

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I. INTRODUCTION

A. BACKGROUND

In today's local area networking environments, users are experiencing problems such as delays in data transmission, interruptions in service, difficulties with relocating workstations, and limited flexibility. [RWS95] Additionally, management of these networks has become labor-intensive leading to high ownership costs.

With the increase in bandwidth hungry applications such as networked multimedia applications, desktop videoconferencing, interactive training, and network-based education on the horizon and the number of users in the average Local Area Network (LAN) environment increasing, shared-media networks with their limitations may become more of a problem than a solution. The need exists for a technology that is scalable and provides a range of link speeds that addresses all conceivable network requirements.

With Asynchronous Transfer Mode (ATM), we are experiencing the emergence of a network technology that maybe able to satisfy the need for a worldwide standard to allow interoperability of information, regardless of the hosts or type of information. [WAI]

Today, in most instances, separate networks are used to carry voice, data and video information because of the difference in characteristics associated with these traffic types. [WAI] As an example, take baseband LANs versus broadband LANs. Baseband

LANs such as Ethernet and Token Ring are much more common in the office environment for transmitting data. On the other hand, broadband LANs utilizing Integrated Services Digital Network (ISDN) are popular where multiple services, such as video, data, and voice are required. With ATM, it is possible that this requirement for separate networks will no longer be necessary. ATM provides a mechanism for communication, which can be used as the basis for both LAN and WAN technologies. ATM is a technology that has been designed from the beginning to accommodate simultaneous transmission of data, voice and video.

It is the authors' opinion that ATM will eventually cause the blurring of the distinction between local and wide area networks forming an integrated network based on one standard.

Because ATM is a switched-based technology, some of the benefits provided are as follows:

- **Reduced Network Bandwidth Costs.** When a packetized form of transmission is used, the bandwidth is allocated to a particular circuit on a packet-by-packet basis rather than on a dedicated basis. Consequently, the network is only being used when there is actual information being transmitted and the "idle" bandwidth may be assigned to other applications.
- **Reduced Network Access Costs.** Rather than requiring dedicated local loops, each capable of handling the maximum burst rate, the local access portion may be shared with several virtual paths using the same local access

loop. This can be very significant considering the fact that local access costs can account for 50% to 70% of the total WAN cost.

- **Reduced Equipment Cost and Commitment.** With ATM, users are not limited to a single technology. Since there are specifications for ATM over frame relay, SMDS and SONET, switches could be configured to support a variety of network services with minimal hassle. Of course, the selection of a WAN technology will be closely tied to the application, but any time there are choices, there is competition and whenever there is competition, price reductions will surely follow. In addition, as bandwidth demands grow, ATM is flexible enough to accommodate higher bit rates without having to replace all existing equipment.
- **Improved Flexibility.** Additionally, ATM provides dedicated bandwidth per connection, higher aggregate bandwidth, well-defined connection procedures, and flexible access speeds. [WAI]

Dedicated bandwidth per connection is achieved in that ATM permits a station to request the allocation of bandwidth on a link for time-sensitive traffic, thereby guaranteeing that there is sufficient capacity for the required quality of service.

Higher aggregate bandwidth is accomplished because of ATM's scalability. As a switched-based architecture, adding additional switches can increase the aggregate capacity of the network.

Well-defined connection procedures involves the transmission of data via virtual channels and virtual paths, which will be elaborated upon more in the next chapter.

ATM networks allow different link speeds to be mixed, so that each user can benefit from access links at an appropriate speed (i.e. 25, 100, 155, or 622 Mbps) for their specific needs.

B. PURPOSE

The purpose of this thesis is to determine the feasibility of ATM as the network technology for the Naval Postgraduate School (NPS) Software Metrics Lab (SML) and design an implementation plan for converting the SML from an Ethernet-based network to an ATM network. Additionally, the purpose of this thesis is to develop a generic ATM lab model.

C. SCOPE AND METHODOLOGY

The focus of this thesis is to review ATM technology as applied to the desktop laboratory computing and research the management, instructional and research benefits that an ATM Lab would provide Naval Postgraduate School (NPS). In analyzing these benefits, the research will entail a review of current books, periodicals, and news articles on ATM technology and interviews with academic and professional specialists.

The research will include reviewing the ATM technology, assessing the SML's current LAN configuration, designing an ideal ATM Lab and developing an implementation plan for upgrading the SML to an ATM Lab.

D. ORGANIZATION OF STUDY

Chapters II and III will provide a basic understanding of ATM technology and an overview of the current network configuration of the SML. Chapter IV will discuss three implementation alternatives within the SML, and the necessary network support required such as management and security. Finally, Chapter V provides the conclusion and recommendations. The following bullets provide a summary of the chapters:

- Chapter I - Introduction. This chapter provides the background for the thesis and states the purpose, scope and methodology, and thesis organization.
- Chapter II - Asynchronous Transfer Mode (ATM) Technology. This chapter will provide a basic overview of the principles and architecture surrounding ATM along with the benefits of ATM.
- Chapter III - Network Configuration of Software Metrics Lab (SML). This chapter presents a physical and logical layout of the SML and its equipment under its current topology. In addition, it identifies the hardware and software components that are necessary for intra LAN communication.
- Chapter IV - Implementation of ATM in the SML. This chapter provides two ATM models or alternatives for implementing ATM in the SML, namely, a "*Parallel ATM LAN*" and "*Internal ATM LAN.*" This chapter also briefly discusses Switched Fast Ethernet as a 3rd, *non-ATM* alternative.

- Chapter V - Conclusion and Recommendations. This chapter provides concluding comments and recommendations.
- Appendices - Here the reader will find three diagrams of SML, a current list of approved ATM specifications, and a glossary of ATM terms and definitions.

II. ASYNCHRONOUS TRANSFER MODE (ATM) TECHNOLOGY

A. INTRODUCTION

1. Purpose of Chapter

The purpose of this chapter is to provide the reader with a basic understanding of how ATM technology works in a User-to-Network environment. Specifically, it is to provide a baseline upon which an ATM model can be developed for the Software Metrics Lab (SML). Essential principles, architectures, and operations are discussed, as well as a comparison of the latest competing technologies. Naval Postgraduate School basic performance issues and benefits of using ATM are highlighted throughout the chapter. For greater technical detail on ATM, refer to the List of References at the end of this paper.

2. Technology Overview

Asynchronous Transfer Mode (ATM), also known as "cell relay" or "cell switching" is a fast, packet-switched, connection-oriented technology designed to transfer multiple types of information and services such as data, audio/voice, video, image and multi-media over a single transmission line. As a transmission protocol, ATM enables these services to be transmitted simultaneously, in real-time, and at speeds ranging from 1.5 Mbps to 622.08 Mbps. Speeds of 2.488 Gbps (for Global/WAN connectivity) are

currently being developed. As a switching technology, ATM has combined the best aspects of circuit switching, packet switching, and frame relay to maximize transmission speeds, throughput, and quality of service (QOS).

With respect to circuit switching, ATM first establishes a dedicated circuit or virtual path connection before it transmits any information. This is analogous to making a Plain Old Telephone System (POTS) phone call and is what is known in the industry as "connection-oriented." With respect to packet switching, ATM "packetizes" information (voice, video, and data) into fixed-sized packets or cells for transmission over virtual circuits. These virtual circuits, unlike shared bus circuits, remain intact until the transmission has finished. These virtual circuits are what enables ATM to avoid the "busy" signals and queuing delays ("latency") common in circuit and packet switching. [WIL96]

Why *asynchronous* transfer mode? The term asynchronous refers to the utilization of cells on a "demand" basis, vice clock synchronization. ATM is based on "asynchronous" time division multiplexing (TDM). In other words, ATM cells do not have a fixed timing relationship or synchronizing clock like traditional TDM.

ATM has been accepted as the "transfer mode of choice" for Broadband Integrated Services Digital Networks (B-ISDN) and is now competing with Wide Area Network (WAN) and Local Area Network (LAN) technologies and even space-based data-links for market share. [CNE, GRE]

The primary advantages of ATM over other competing network technologies such as Gigabit Ethernet and LAN switching are:

- Bandwidth-On-Demand
- Guaranteed Quality Of Service (QOS)
- True Scalability
- Computer and Telephone Integration (CTI)
- Compatibility with existing infrastructures
- Processing Efficiencies

These advantages will be explained in depth further in the chapter. [TAY, ENC, MEN]

B. PRINCIPLES AND ARCHITECTURE

1. ATM Cell Structure

As mentioned earlier, ATM is a packet switching, connection-oriented technology, and relies on fixed-length cells of 53 octets (bytes) each to carry information from end-to-end. Each cell contains a 5-octet header for addressing, and 48 octets for information or "payload." See Figure 2.1 for cell/header structure in a User-to-Network interface (UNI).

The overhead of the 5-octet header is very small when compared to other technologies and was easily accepted by the International Telecommunications Union (ITU). On the other hand, the 48-octet payload became a standard only after much debate

over cell efficiency and "packetization delay." One school of thought pushed for a 64-octet sized cell to achieve efficiency (to "fill" cells with as much information as possible), whereas another school of thought pushed for a 32-octet sized cell to reduce packetization delay (time it takes to fill a cell with digitized voice samples - 64Kbps). In the end, the two groups compromised on the fixed-length, 53-octet sized cell so that the latency or delays inherent to one type of traffic (video for instance), wouldn't affect another type of service (data, voice). These fixed-length cells, unlike the variable-length packets of frame-relay and packet switching, are what make ATM deterministic and reliable. [FRE, RYA, COX]

2. Cell Header Format

The 5-Octet cell header is discussed here primarily because it is essential for understanding the basic operation of ATM technology, and because it is the critical component of the ATM cell. The header not only provides the identification of the connection being made (vice the entire destination address), it ensures each different application obtains the necessary QOS. The cell payload, on the other hand contains only the information being transferred and is transparent to the ATM network. A basic description of the functional components of the cell header is provided below and in Figure 2.1. For a more detailed discussion of the operation of the ATM cell header, see Freeman, 1998 [FRE].

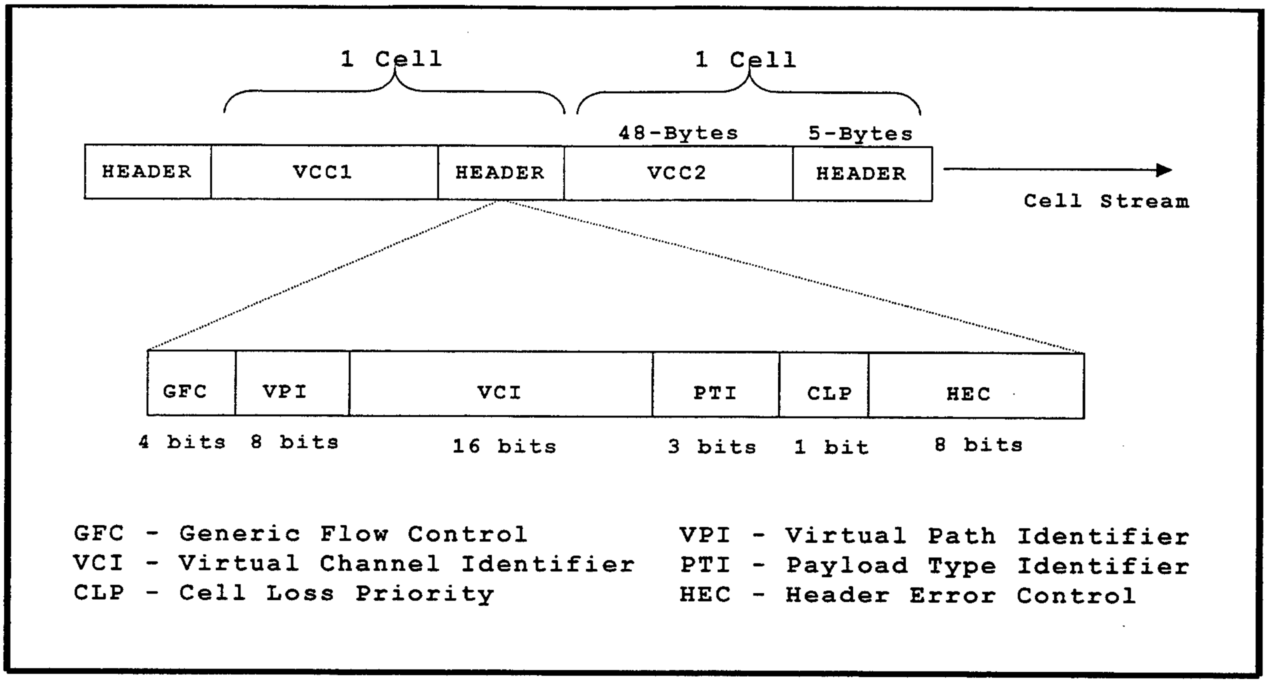


Figure 2.1 ATM Cell Structure

a) Generic Flow Control (GFC)

GFC field consists of 4 bits and is assigned to regulate local flow control, on the customer side in an ATM network. The GFC value is not carried end-to-end and is overwritten by ATM switches.

b) Virtual Path Identifier (VPI)

The VPI is the first part of the 24-bit routing field used for routing the cell. The VPI consists of 8 bits and specifies a virtual connection through various ATM

network switches and other devices. VPI values are preassigned. When a virtual path has been established, it can support multiple virtual channels specified by the VCI.

c) Virtual Channel Identifier (VCI)

VCI is the second part of the 24-bit routing field and consists of 16 bits, which designate the actual communication channel that data will follow. Like VPI, VCI values are pre-assigned. Additionally, multiple virtual channels can be active simultaneously over the same virtual path.

d) Payload Type Identifier (PTI)

PTI consists of 3 bits and indicates the type of information (data, voice, and video) carried in the 48-byte payload section of the cell. PTI can differentiate between "user" and "non-user" cells.

e) Cell Loss Priority (CLP)

CLP is only 1 bit long, which indicates the priority or significance of the cell. If cell CLP value is set to 1, then it can be discarded during heavy traffic flows. Frame relay uses the same CLP concept.

f) Header Error Control (HEC)

The HEC field consists of 8 bits and is capable of single-bit error *correction* or multiple-bit error *detection.* HEC covers the entire cell header, but is not always invoked, depending upon the transmission system being used (i.e. fiber-optic).

3. ATM Architecture

An ATM network architecture consists primarily of end nodes and switches and resembles more a telephone voice network than data network.

The ATM structure falls under the B-ISDN Protocol Reference Model (PRM) and is organized into three planes and three layers, which specify the domain's activity (see Figure 2.2 for overview). The three planes consist of the *Control Plane* (the lowest plane in the hierarchy) which contains signaling information and is responsible for call and connection control, the *User Plane*, which is responsible for transporting user information, and the *Management Plane (*the highest plane in the hierarchy) which contains layer and plane management functions. Since we are primarily concerned with the ATM User-to-Network interface (UNI), these planes will not be discussed any further. For greater detail on ATM planes and for a comparison of this architecture (B-ISDN) to the seven-layered OSI model, see Williams, 1996 [WIL].

The three B-ISDN PRM layers consist of the ATM Adaptation Layer (AAL), the ATM Layer and the Physical Layer. These layers are primarily responsible for preparing the cells for data transmission and reception, as discussed below and under "ATM Operation," section C.

a) ATM Adaptation Layer (AAL)

The AAL is the "top" layer of the ATM architecture and consists of two sub-layers, the Segmentation and Reassembly (SAR) sub-layer and the Convergence Sublayer (CS). The SAR is responsible for the segmentation and reassembly of

information (data, voice, and video) that is "stuffed" into the 48-byte sized payload and transmitted at various speeds (bit rates). This layer provides the protocol required to interface with the different types of traffic connected to ATM networks (e.g. Ethernet, Frame Relay). The Convergence sub-layer is responsible for time and clock recovery and message identification. Additionally, AAL has five protocols which correspond to the four different classes of ATM service which will be discussed later in this chapter.

b) ATM Layer

The ATM layer provides flow control and adds (or removes) the 5-byte cell header to the payload to ensure the payload gets on a correct virtual connection. Here, cells of different logical connections are multiplexed (or demultiplexed) into a single cell stream on the physical layer. This layer then translates cell identifiers to allow data to flow from physical link to physical link.

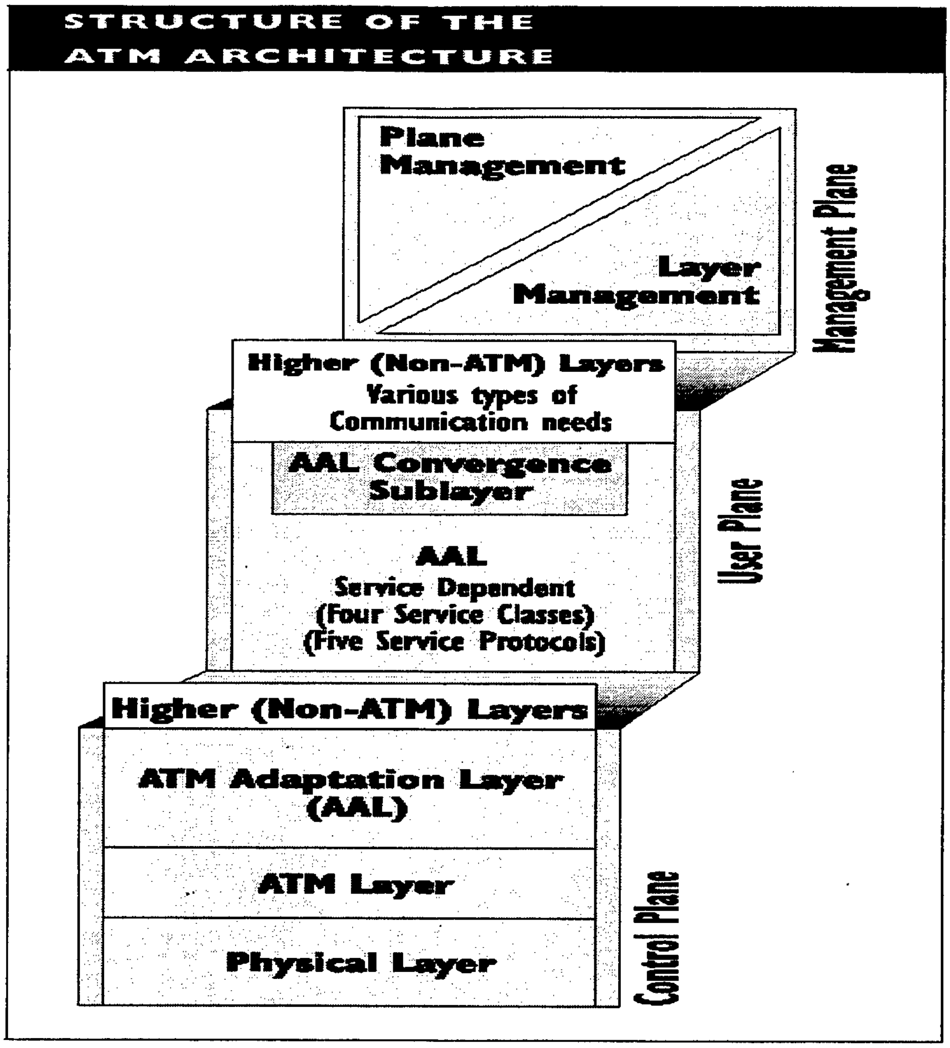


Figure 2.2 ATM Layered Architecture [VAN]

c) Physical Layer

The Physical layer is the lowest layer of the system and converts electrical or optical signals of the cell stream into bits to be transferred over various physical media such as CAT5, Coax, and fiber. Error correction of cells is also conducted at this layer.

d) Interfaces

Following are the three ATM interface standards, which can be used with ATM networks:

- User-to-Network (UNI) - Enables the end-user to access or connect to the network via an ATM switch. This standard assures that customer routers, hubs and ATM switches will be compatible with the public ATM network service. It is this interface that will be used to develop an ATM model for SML.
- Network-to-Network (NNI) - Also known as "Network-to-Node" interface, connects networks together and makes routing possible. This standard provides additional flows of management data beyond UNI.
- Broadband-InterCarrier Interface (BICI) – BICI is a carrier-to-carrier interface (similar to private network-to-network interfaces) that supports permanent virtual circuits between carriers. The BICI standard will allow end-to-end management of interconnected networks by allowing the exchange of "management, configuration, and performance" data required when connecting public networks. [RYA97]

e) Classes of Service

There are four standard classes of service based on the type of data transferred, with attributes measured in three ways: how much delay, type of connection

required, and the timing and synchronization of the source and destination. See Table 2.1 for an overview.

Class	A	B	C	D
Media Type	Voice/ Video	Packet Video	Data/IP (X.25)	Data (SMDS)
Bit Rate	Constant	Variable	Variable	Variable
Connection Mode*	C-O	C-O	C-O	C-L
AAL	AAL-1	AAL-2	AAL-3/4 (AAL-5)	AAL-3/4
Protocol Data Units (Bytes)	47	45	44	44

* C-O: Connection-Oriented
C-L: Connectionless

Table 2.1 Classes of Services

C. ATM OPERATION AND CONNECTIVITY

1. Basic Operation

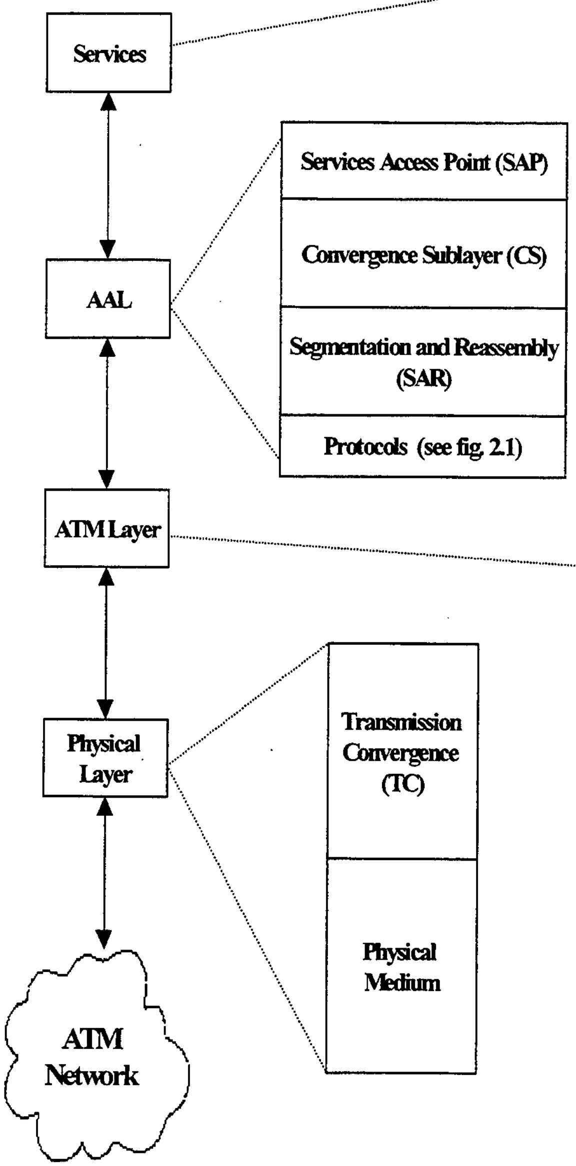
See Figure 2.3 for basic operation. For greater detail, refer to Freeman. [FRE]

2. Basic Connectivity

Since ATM has a switched, point-to-point topology, a connection must first be established between sending and receiving nodes before information can be transmitted. The ATM switches cooperate to find the best route to the called node and set up a virtual connection. When the connection is established, the ATM switch nearest to the calling node provides a virtual channel connection number identifying the connection.

The ATM connection is a logical connection known as a virtual channel (similar to the switched virtual channel of X.25) and is identified by the virtual channel identifier (VCI) in the cell header. The VCI is 16 bits (2^{16}) long and can identify up to 65,536 virtual channels (see Figure 2.1).

Switching nodes throughout the network maintain channel information and interpret the VCI to determine which port to forward the cells (this is in contrast with a shared media like Ethernet, where data is broadcast over the medium). If these channels



Data, Voice, Video. For example, voice data is encoded into digital form using pulse-code modulation (PCM)

CS provides interface for various services above. Users connect to this layer via the SAP. No PDU's are defined here because data passing through is service dependent.*

SAR packages variable-sized packets into fixed-sized cells when transmitting and reassembles cells at receiving node. Also manages cells that are out of order or lost.

This layer is service independent. Creates cells and uses physical layer to transmit them. Virtual paths are defined and given unique identifiers (VCI) and then cells are multiplexed (or demultiplexed) during transmission.

TC is responsible for making sure valid cells are being created and transmitted - breaks off individual cells from data stream of ATM layer, checks the cell's header and encodes bit values.

Physical layer defines medium and bit-timing capabilities (can use optical SONET, DS3 and 100/155 Mbps - developing standards for CAT3 UTP). Provides error correction and routing.

* Protocol Data Units (PDU's) become the payload for cells that are transmitted.

Figure 2.3 Basic ATM Operation

have the same transmission and receiving nodes, they can be consolidated into virtual paths, similar to a permanent virtual circuit in X.25. The path defined for any given connection remains variable. These virtual paths are identified in the cell header by a virtual path identifier (VPI) which, for a UNI, is 8 bits long (for NNI the VPI field is longer by four bits).

A major advantage of using virtual paths and circuits is processing efficiency. Cell headers do not have to contain the full address of the destination, but rather only the identification of that connection. Consequently, data can be routed and forwarded faster than other network technologies.

D. COMMON IMPLEMENTATIONS AND APPLICATIONS

Today, ATM applications continue to expand and are currently found in the educational, scientific/research, business and transportation industries. Perhaps one of the most unique ATM applications is for the support of deep-sea exploration. The Monterey Bay Aquarium in California feeds live video, picture-in-picture video, and data simultaneously over an ATM link to a technology museum 90 miles away. The aquarium receives the live video/data stream via a microwave feed from a ship off-shore and the ship receives the live video and data feed via fiber-optic cable from a remote-controlled submersible vehicle 6000 feet below the ship! What is remarkable is that this is all done in real-time, without satellites! The *interactive* educational and scientific benefits of ATM technology are tremendous.

Common implementations of ATM include:

- Router-ATM-Router. Use ATM switch between routers to increase inter-router bandwidth.
- ATM Workgroups. Connect ATM Workgroup to existing network to maintain connectivity to backbone and Internet.
- LAN Backbones. Legacy networks using Ethernet or Token Ring can connect to an ATM backbone via "edge devices." The advantage of this approach is that ATM speeds of up to 622 Mbps can be delivered throughout the infrastructure, from LAN to WAN. LAN emulation (LANE) is required for this legacy-to-ATM connectivity.
- Back-end ATM Network (Inter-Server). This implementation of ATM is used primarily for "off-loading" existing network traffic and maximizing inter-server throughput so that more bandwidth will be available to other nodes. [ADA] See Figure 2.4 below.

In the future, NPS will have an architecture similar to Figure 2.5 below.

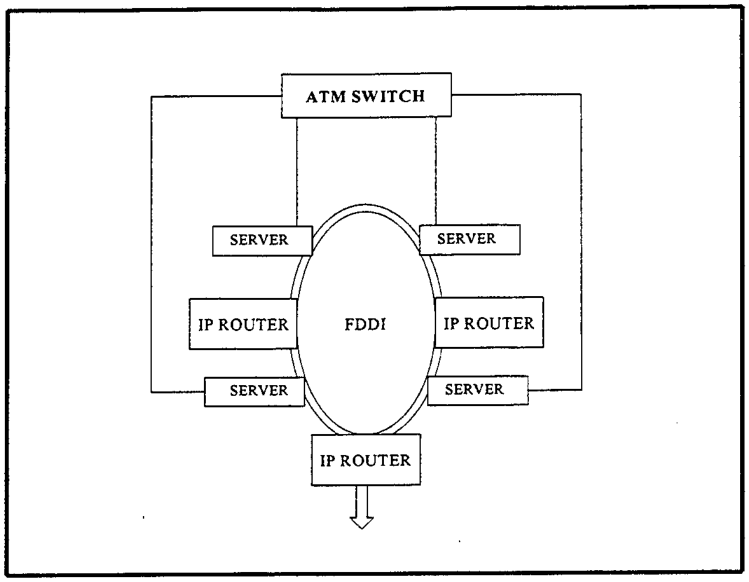


Figure 2.4 Back-End ATM Network (Inter-Server)

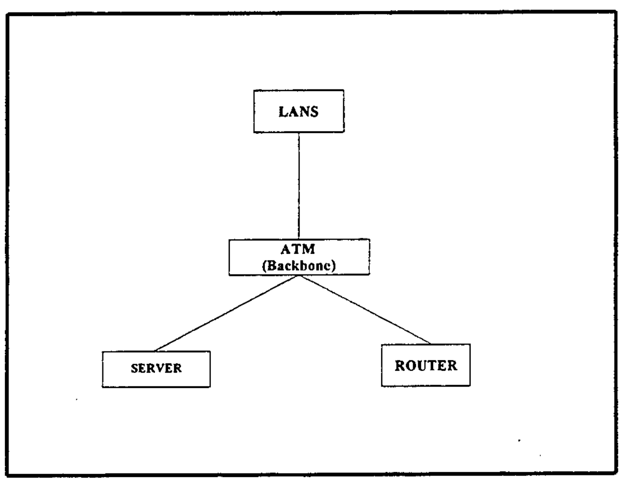


Figure 2.5 Future NPS Network (with ATM Backbone)

Other important applications of ATM are listed below:

- Global Backbone to Information "Superhighway"
- Desktop video teleconferencing (Video-on-demand)
- High Resolution Modeling and Visualization
- Telemedicine (and Medical and X-Ray Imaging)
- Network Based Education (NBE) and Research ("NovaNET")
- Distributed Supercomputing and Database Management
- Concurrent Engineering and CAD/CAM
- Interactive Computing and Network Gaming

E. BENEFITS OF ATM TECHNOLOGY

1. True Scalability

ATM scalability means that the amount of bandwidth required for a given application at a given time can be tailored to a user's needs (i.e."bandwidth on demand"). The ATM cell-based structure is the key to ATM scalability in that the size of each cell remains constant during a connection over an ATM network. This guaranteed cell structure allows data, voice, video and high-speed applications to be integrated and carried simultaneously over a common link (cable, coax or fiber) at variable speeds.

2. Processing Efficiency

Routing is simple because ATM is connection-oriented. ATM can route and forward data entirely in hardware, "achieving data handling cost efficiencies that are orders of magnitude greater than software-intensive routers." Additionally, an ATM technique known as Multi-protocol Over ATM (MPOA) has introduced "Zero-Hop" routing, which establishes virtual routes or "shortcuts" across an ATM network greatly increasing performance (compared to legacy routers which introduce delay caused by performing address resolution, route determination and packet filtering at every node on the route). [TAY, RYA]

3. End-to-End Quality of Service (QOS)

The ATM cell header not only identifies the recipient of the data, it also prioritizes cells and orders the QOS. QOS ensures that bandwidth, time and resources will be available for the duration of an application's needs (for example, transmission of delay sensitive traffic such as a live video presentation across a WAN). QOS is determined by delay, throughput, jitter, and the probability of losing data in a network. [COX94]

4. Flexibility

Due to ATM's scalability and point-to-point circuits (vice a shared bus), it can be operated over great distances, in both WAN's and LAN's. In an all ATM network, connectivity between a LAN and a WAN would be enhanced. [MUL, SUB]

5. Computer Telephone Integration (CTI)

ATM will allow companies to integrate their computer and telephony (telephone and fax) networks, greatly reducing network overhead. Today, call centers are taking advantage of this capability.

6. Other Benefits of Using ATM Technology:

Compatible with existing networks (i.e.: Cable, Fiber, Ethernet, Token Ring) and has an "open-ended growth path - Not locked to any physical medium or speed." [SUB]

F. CHAPTER SUMMARY

The characteristics of ATM discussed here serve as a foundation for this research and will be referred to occasionally. Of particular importance is the discussion on interfaces, connectivity (sections B3 and C1 and C2, respectively) and application environments which will determine the type of model possible for the SML.

See the glossary (appendix C) for key terms and definitions discussed here and in the remainder of the paper. [CIS, CLE, ENC]

III. NETWORK CONFIGURATION OF SOFTWARE METRICS LAB (SML)

A. INTRODUCTION

1. Background

The Software Metrics Research Center and Laboratory (SML) was established at the Naval Postgraduate School to facilitate the conduct of research on software metrics and the development of software metrics tools. Software metrics tools are being utilized to improve the quality of software products and productivity of software developers and maintainers.

In addition to software metrics research, the lab has been used for several years for the teaching of IS3503 Microcomputer Networks and recently for the teaching of IS3020 Software Design As such, the lab is considered both a research and an instructional lab, which makes it a viable candidate for employing ATM technology to the desktop to further enhance its capabilities in these areas.

2. Purpose of the Chapter

This chapter will provide an overview of the current network architecture employed within the SML. The chapter presents a physical and logical layout of the SML and its equipment under its current topology. In addition, it identifies the hardware and software components that are necessary for intra LAN communication.

B. CURRENT NETWORK ARCHITECURE

1. Physical Topology

Topology is the manner in which nodes are interconnected in a computer network. The SML is configured as a Star Wired Bus-Ethernet/IEEE 802.3 10BaseT. In other words, the lab's topology is a physical star (i.e. stations are connected to a central hub) and logical bus (i.e. demand access, broadcast protocol) utilizing category 5 (CAT 5) unshielded twisted pair (UTP) cabling as the media. This configuration is common in most LANs today. See Figure 3.1 and Appendix A-1 for a pictorial representation, and overview, respectively.

2. Existing Equipment

As Figure 3.1 indicates, the SML currently consists of 15 personal computers, one acting as a server, connected to a 16-port Ethernet 10BaseT hub and one network printer. The lab is wired with CAT 5 four-pair UTP. Since the lab utilizes a non-switching 10BaseT hub, the bandwidth capacity is limited to 10Mbs and is shared among all users on the LAN. However, with the CAT 5 wiring, the lab has the potential for future expansion to Fast Ethernet (100Mbs) with the proper equipment installed.

The SML's personal computers are comprised of two 486 computers and 13 Intel Pentium computers. The client computers are identified as Metrics 1 through 14. Each computer is equipped with one of the following types of network interface adapters: Fast Etherlink PCI 10/100 BaseT, Etherlink II 10MB or Fast Etherlink XL PCI 10/100 MB.

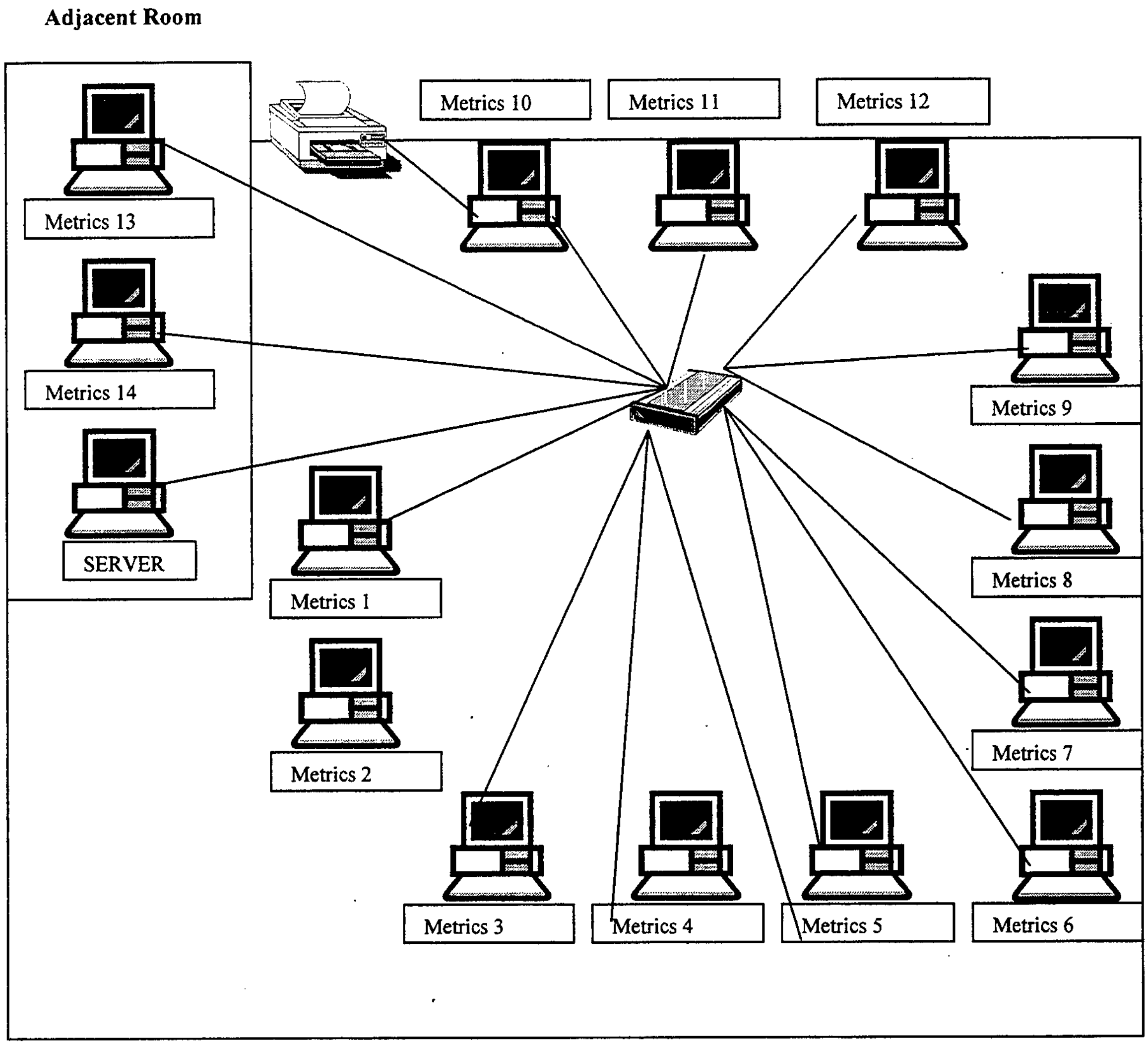


Figure 3.1 Software Metrics Laboratory Network

3. Software/Protocols

The SML Server has Microsoft Windows NT Server 4.0 installed and each client computer has Windows NT Workstation 4.0 installed. The protocols that are used within the lab to enable intra-LAN communications and access to the Internet are TCP/IP, NWLink NetBIOS, NWLINK IPX/SPX, and NetBEUI. As a research and an instructional lab, SML maintains an abundance of software. The following applications are installed in the SML:

- SMERFS (software reliability prediction models)
- Statgraphics
- S-Plus
- WordPerfect Presentations
- MS Office 97 Suite
- Internet Explorer
- TCP/IP Suite (FTP, PING, Telnet, TN3270, and SMTP)
- BOCS (object-oriented design tool)
- Extend 4.0

The following software was installed on previous equipment in SML and will be reinstalled on the new equipment:

- Datrix (metrics analyzer for Pascal programs)
- COCOMO cost model
- Simscript
- GPSS
- Mathematica
- Mathcad

[Network tutorials and an encyclopedia are installed for instructional purposes]

C. CONNECTIVITY TO CAMPUS BACKBONE

1. Fiber Distributed Data Interface (FDDI) Backbone

In the hierarchical scheme of distributed systems, the campus backbone is the top-level, or central, connection path shared by the nodes or networks connected to it.

The backbone manages the bulk of the traffic and it may connect several different locations, buildings, and even smaller networks. For this reason, the backbone often uses a higher speed protocol than the individual LAN segments. [ENCY] Because of the high bandwidth requirements associated with backbones, fiber optic cabling is often used. NPS currently employs an FDDI Campus Backbone. The SML gains access to the backbone via a wall plate installed within the lab. The wall plate connects to a patch panel, which then ties into the backbone. The cabling utilized to provide connection from the lab to the patch panel is CAT 5 UTP wire. With this arrangement, information passed outside of the lab is at the same rate as information passed within the lab, up to the connection to the backbone, 10Mbps. The rate between nodes on the backbone is 100Mbps.

2. ATM Backbone

NPS is currently in the process of upgrading to an ATM campus backbone that will provide ATM speeds up to 155 Mbps to the lab. SML's connectivity to the ATM backbone will remain the same as the FDDI backbone with the exception of the increased access speed.

Even with the migration to an ATM backbone, the capabilities and features associated with ATM will be lacking within the SML.

D. CHAPTER SUMMARY

This chapter has presented the network configuration of the SML and the hardware and software that is employed within the lab. Additionally, a description of how the lab currently connects to the FDDI campus backbone and how the lab will connect to the ATM campus backbone has been provided.

The information presented in this chapter is pertinent in implementing ATM desktop laboratory computing within the SML, because it provides a basis for determining the feasibility of installing ATM to the desktop. The next two chapters will illustrate the applications of ATM to the desktop networking within the SML first, from an idealistic approach and then from a more practical approach.

IV. IMPLEMENTATION OF ATM IN THE SML

A. INTRODUCTION

Having described the operational concept of ATM and the physical layout of the SML's network infrastructure, we will now develop an implementation model for incorporating ATM within the SML.

Our initial model had the SML configured with ATM to the desktop and direct connectivity to the campus backbone. During the course of our research, we learned from International Automation Associates (IAA), the contractor that is installing the campus ATM backbone, that "no user-controlled devices will be permitted to connect to the campus backbone." The reason for this restriction is fear that the user or the user-controlled device could potentially bring down the campus' production network.

We discussed other alternatives with Doug Picard, president of IAA for implementing ATM to the desktop. We agreed on the following alternatives: either create an additional network that *parallels* the campus production network or implement an *internal* ATM LAN within the SML without connectivity to the campus backbone. These two alternatives are the most feasible today for implementing ATM to the desktop in SML. In addition to these two alternatives, a third alternative, and perhaps more practical, is implementing Switched Fast Ethernet (with an ATM Backbone) to the desktop.

The purpose of this chapter is to discuss these alternatives, and provide the requirement specifications (i.e. hardware and software) necessary for the implementation of each alternative.

B. EVALUATING SML'S NETWORK PERFORMANCE REQUIREMENTS

One of the first steps in developing a network is to have some method or tool for determining the current as well as the anticipated network load. This enables the evaluation of whether or not the network technology that is being proposed will accommodate the network's capacity. In our evaluation of the SML's network load, we performed a performance experiment in SML.

The SML experiment consisted of several test runs where applications were simultaneously launched, and the time for all PCs to load the application was measured.

1. Estimating the SML's Load

Although the primary objective of ATM in SML is to provide a vehicle for instruction and research in ATM technology, the upgraded network must be able to handle the SML maximum load. That is why we have included this section to provide some data on the current load demands of the SML. We anticipate that after implementing ATM in the SML, there will be a need to run more high bandwidth applications such as desktop videoconferencing, interactive computing, or network based education (NBE) thus increasing its load.

2. The SML Experiment

Our SML experiment was conducted using three individuals operating 12 PCs. The experiment was "near simultaneous" because there was some delay in actually launching an application simultaneously on all 12 PCs.

The scenarios consisted of the following runs during the lab experiment: 1) launching Microsoft Internet Explorer, 2) accessing Network Neighborhood, and 3) launching Microsoft Internet Explorer with Office '97 applications opened (i.e. Access, Word, PowerPoint, and Excel) on all 12 PCs. For the last scenario, only nine PCs were available for testing. The following table shows the results.

SCENARIO	TIME (seconds)
Launching MS Internet Explorer	
Run #1	15.0
Run #2	10.2
Run #3	9.40
Accessing Network Neighborhood	9.20
Launching MS IE with Office '97 Applications Opened	11.4

Table 4.1 Lab Experiment Results

The launching of MS Internet Explorer was run three times to see whether the results were consistent – they were. These results provide a bound on performance: any network technology that is considered should produce equal are better times. For

additional information on estimating network load capacities, see *Local Area Network Performance* by Gilbert Held. [HEL]

C. IMPLEMENTATION ALTERNATIVES

1. Parallel Network

Because the campus backbone is considered a production network, no user-controlled ATM devices are permitted to connect directly to the backbone. In order to implement ATM to the desktop and have some connectivity outside the SML, a research network parallel to the campus backbone has been proposed (see Appendix A-2). This network will afford NPS students and faculty from the various curricula the opportunity to experiment with ATM without the danger of bringing down the campus production network. Additionally, this option would allow ATM connectivity between SML and other subnets on campus (or even off campus) without interfering with the NPS production network. Some of the research that will be available for students and faculty include researching the impact of ATM cells traveling across a variety of transmission mediums, testing the "limits" of virtual private networks (VPN's), and measuring the survivability of cells during link outages.

The implementation of this network is beyond the scope of this thesis. Our main concern is how will the SML be configured with ATM to connect to this network? We did make some assumptions regarding this network: (1) It will have an ATM backbone similar to the production network backbone, (2) It will be connected using fiber optic cabling throughout, and (3) Only experimental and research labs will be connected, no

production labs will have access. This will ensure that if an experiment goes awry, the production side of the campus will not be affected.

We believe that the parallel network would be the *ideal* approach for implementing ATM, however because of budget constraints, we feel that it is the least likely of our alternatives to be implemented.

a) Implementation Issues

(1) Hardware. Some of the major concerns about implementing ATM are interoperability and reliability of the various vendors' products. Additionally, the products presented in this chapter were required to be compatible with industry standards such as LAN Emulation (LANE) V1.0 and User-to-Network Interface (UNI) 3.0 and 3.1, and be able to operate in a multi-protocol LAN environment. From the ATM switch standpoint, we also looked for some form of management capabilities for maintaining the ATM LAN.

One device that we used for evaluating the ATM Network Interface Card's (NIC) compatibility is the Windows NT Hardware Compatibility List (HCL). Since the NICs are the only components that operate with the operating systems in a LAN, they are the ones that may cause compatibility problems. The HCL not only provided an evaluation method for compatibility, but also provided a gauge for measuring the "maturity of the ATM technology." [INT] The peripherals listed on the HCL all passed rigorous compatibility testing with Windows NT 4.0. [WIN] Surprisingly, this list was not as lengthy as we

might expect. As of August 17, 1998, the following companies were listed on the Windows NT HCL: *Adaptec, Fore Systems, Madge*, and *Olicom*. This does not necessarily mean that other companies' products are not compatible with Windows NT. What it does mean is that if a driver is not listed in the HCL, it will have to be acquired from the manufacturer.

We were not as concerned about interoperability among ATM switches since the SML will require only one switch. However, with the upgrading of the campus backbone to ATM, we did have questions regarding interoperability among the switches being employed in the backbone and the switch installed in the SML. To obtain this information regarding interoperability among ATM switches, we had to question various representatives from several ATM companies. It should be noted that the majority of the companies in the ATM market are promoting ATM products that are interoperable with their competitors.

(2) Software. From a software standpoint, we were primarily concerned with what software is installed in a switch. To have a fully functional ATM LAN, the following software components are required either in the switch or a stand-alone host, LAN Emulation Server (LES) and Broadcast and Unknown Server (BUS). The LES automatically maps MAC addresses to ATM addresses. When a client needs to transmit to a specific MAC address, the LES notifies the client of the ATM address of the target host. The BUS handles all broadcast traffic and traffic destined for unknown ATM

addresses. Each host had to be configured with a NIC that supported LAN Emulation Client (LEC). The LEC is what emulates the MAC layer, intercepting all transmitted data and passing on received data. Another component that we looked for that is optional in an ATM LAN is LAN Emulation Configuration Server (LECS). LECS directs the LEC to the appropriate LES. Each of these software services had to support LANE V1.0.

b) Hardware Requirements

In determining the hardware and software necessary to implement ATM, one must first determine what speed will be sufficient to accommodate the network. Currently the only two available ATM speeds supported by vendor products are 25 and 155 Mbps, with 155 rapidly becoming a standard. Since we are presenting an ideal model here, the 155 Mbps ATM speed will be used to determine the necessary hardware.

(1) The ATM Switch. The first and most important piece of equipment to consider is the switch. In our research of available ATM switches, we discovered that the majority of ATM vendors are producing ATM switches to support an ATM campus backbone. However, there were a few vendors that produced ATM workgroup switches for ease in implementing ATM to the desktop. Therefore, the information presented in this section will pertain to ATM switches meant for workgroup applications.

As mentioned in the implementation issues section, some of the characteristics we considered during our research are interoperability, reliability and scalability. Additionally, as was mentioned in chapter two, ATM is a connection-

oriented technology and in order to co-exist in a legacy LAN environment, it must use one of two mapping standards, Classical IP (CIP) or LAN Emulation (LANE). It is by using these mapping standards that legacy LAN applications are able to run transparently over ATM and enable ATM hosts to transparently talk to Ethernet and Token Ring hosts. Because the SML utilizes multiple protocols (i.e. NetBEUI, TCP/IP, and NWLink IPX/SPX), the mapping session that is most appropriate is LANE. With this in mind, the switches we researched had to provide support for LANE.

We have established the fact that our ideal ATM LAN will consist of ATM-155 (OC-3) with fiber to the desktop. In today's ATM market, ATM switches come in two varieties, fixed-port and modular. With the SML having 15 PCs (including the server), we researched those switches that could accommodate 16 nodes or had the capability of expanding to 16 nodes.

(2) The ATM Network Interface Card (NIC). The second most important component for implementing ATM is the NIC, or more commonly called the network adapter card. Because there are 15 PCs, 15 NICs with the LECs software will be required for the SML.

Another issue concerning ATM NICs is the network computer's bus structure (i.e. Sbus, PCI, ISA, Micro Channel, etc) supported by the NIC. The computers in the SML are capable of supporting either PCI (Peripheral Computer Interface) or ISA (Industry-Standard Architecture). The PCI is faster than ISA and has

been expanded to 64-bits to meet the need of the Pentium processor. Therefore, our research only involved ATM NICs that supported the PCI bus structure.

The following table provides a list of the required hardware and cost associated with each for implementing an ATM LAN within the SML under the parallel network alternative.

FIXED-PORT		
COMPONENTS	Unit Price	Extended Price
16-port Switch, MMF Configuration	$8,204.95	$8,204.95
155 (OC-3) PCI, MMF Adapter (15)	$605.95	$9,089.25
62.5/125 micron GP optical fiber bulk, 500ft	$299.95	$299.95
Total	$9,110.85	**$17,594.15**
MODULAR		
5-slot Chassis Switch	$1,944.44	$1,944.44
4-Port ATM module, OC-3, MMF (4)	$1,944.44	$7,777.76
155 (OC-3) PCI, MMF Adapter (15)	$605.95	$9,089.25
62.5/125 micron GP optical fiber bulk, 500ft	$299.95	$299.95
Total	$4,794.78	**$19,111.40**

Table 4.2 ATM Hardware Costs

Again, the above table does not reflect the connectors and adapters required for either the fiber optic cabling or the necessary equipment for installing the cable. Additionally, the prices are averages of reseller's prices for the given product. So the final cost for either implementation may be below or above what is stated here. From reviewing the table, one can see that the prices associated with the fixed-port switch and

the modular switch are about the same. The modular switch, based on the number of slots available, does afford the opportunity for expansion. In this particular case, the modular switch could accommodate up to 20 nodes.

c) *Software Requirements*

The most important software required is the driver for the particular ATM adapter card, whether it was already incorporated into a specific operating system or provided by the ATM manufacturer. The vast majority of the switches that we researched came equipped with the necessary internetworking software to support LANE services, Private Network-to-Network Interfaces (PNNI), and User-to-Network Interfaces (UNI). Additionally, almost every switch possessed some form of management software for providing dynamic status, statistics, and configuration information for the switch.

2. Internal ATM LAN

The implementation issues, hardware requirements, and software requirements discussed for the parallel network alternative are similar for the internal ATM LAN alternative. With this alternative, the ATM LAN would be limited to the SML with no connectivity to other LANs. However, with this alternative the existing Ethernet LAN would be maintained in order to provide connectivity to the Internet that the internal ATM LAN would not provide. This alternative will allow students and staff to experiment with the technology in a local environment only. This alternative is considered a more practical approach to implementing ATM to the desktop because it

would not require the implementation costs associated with a campus-wide parallel network.

With this approach, the switch would be isolated from the current subnet in SML and would form it's own network, as depicted in Appendix A-3. To maintain SML's current physical star and logical bus architecture, UTP CAT 5 or fiber optic cable would have to be installed between every computer (and server) and the ATM switch. PC's would be required to have two network adapter cards and associated drivers to operate under this architecture. Advantages of this option would allow students to get "hands-on" ATM switch training as well as experiment with different load configurations and protocols without directly impacting current SML subnet or school's ATM backbone. By means of this training, students would be prepared to manage and make sound decisions regarding ATM technology at their commands, as outlined by the Navy's IT-21 initiative. [CIN]

Disadvantages of this option would be primarily the cost of ATM equipment and the complexity of managing two separate LAN's. Obviously, the majority of the cost would be in the switch itself, with additional cost resulting from the extra adapters, drivers, connectors and labor required for implementation. Of special note, the average price of ATM LAN switches is still very expensive compared to traditional network technology, but prices are starting to decrease.

With respect to connectivity *within the SML*, this option is similar to the parallel network (see Appendix A-2). However, this option will allow for the use of UTP cabling

between the ATM switch and NICs, whereas with the parallel network alternative, fiber optic cabling will be required.

a) Hardware Requirements

The internal ATM LAN option would take advantage of a modular, 155 Mbps ATM switch since most 25 Mbps switches are being phased-out. [PHO] The reason for a "modular" switch, vice "fixed-port" is to allow for flexibility and future network expansion in SML. This option would implement the same ATM modular switch used in the parallel network, but would support modules compatible with UTP or multi-mode fiber (MMF). Specifically, an example of the basic hardware required and associated costs for this option can be found in Table 4.3 (adapter prices in this table have been averaged across five major ATM vendors from 17 August to 01 September 1998):

Components	**Unit Price**	**Extended Price**
155 Mbps UTP5 16-Port Switch (Fixed Port)	$4,364.95	$4,364.95
UTP5 Copper Media PCI Adapter (15)	$585.39	$8,780.85
Fast CAT5 UTP Plenum Cable (500' Bulk)	$199.95	$199.95
Total	**$5,150.29**	**$13,345.75**

Table 4.3 ATM Hardware Costs

Note that in Table 4.3, the cost of a fixed-port, vice a modular port is provided to illustrate the wide range in prices between switch types reflected in Table 4.2. To implement a modular switch with UTP modules, the price was nearly double that

of the fixed-port switch. Although flexibility is limited, for small LAN's such as the SML, a fixed-port ATM switch can be justified. Depending on the type of research conducted and the potential for growth, the fixed-port switch is probably more cost-effective as well.

b) Software Requirements

Software requirements for the internal ATM LAN option remain the same as in the parallel network. Specifically, the switches we researched were supported by many LANE, PNNI, UNI and management services. For SML, all drivers must be compatible with Windows NT 4.0 since that is the network operating system outlined by IT-21. Determination of particular services and functionality is beyond the scope of this thesis. For example, a PCI driver supporting Windows NT 4.0 can be configured to support "Simultaneous LANE", "Up to 4 LANE Clients", "Single...Client", or "Support for 1 adapter per system." Then, given the type of operating system installed (NetWare 4.1, DOS, OS/2 Warp, MacOS or Windows 95) and bus platform used (Sbus, PCI, EISA, VME, GIO or Micro-Channel), the configuration alternatives become very complex.

3. Switched Fast Ethernet with ATM Backbone Connectivity

Due to limitations previously discussed, this is perhaps the most *realistic* option for upgrading SML because, combined with an ATM backbone, greater network performance could be achieved without changing the basic network technology (Ethernet). Switched Fast Ethernet would significantly increase the performance *within*

SML and provide enough bandwidth to support most applications currently available today.

Conversion of SML from a 10 Mbps Ethernet to a 100 Mbps Switched Fast Ethernet network would be relatively simple. Specifically, only the hub and PC NIC adapters (including server) would have to be replaced by 100 Mbps compatible hub and adapters. However, 10 Mbps speeds could continue to be supported as long as Fat Pipes (high-speed uplink ports) were installed. This configuration in SML would be known as a "Desktop Switched Fast Ethernet." [PCW, IBM]

An example of Switched Fast Ethernet prices (as of 16 Sept 98) can be found in the Table 4.4 below:

Device Interfaces	**Fast Ethernet Costs**
Adapter (Single Interface-UTP)	$150.00
Fast Ethernet Switch	$1000.00
Compatible Router (Optional)	$7000.00
Redundant Transceiver (Optional)	$650.00 (UTP)/$1000.00 (MMF)

Table 4.4 Typical Prices for Switched Fast Ethernet Devices [CIS]

D. NETWORK SUPPORT

1. ATM Network Analysis and Management

The primary goal of network analysis and management is to ensure "maximum network uptime" and determine and isolate problems when they occur. Network managers do this by using special ATM Broadband testing equipment to perform the following analysis:

- *Standards Testing*. Verify interoperability and compliance with ATM Forum standards by testing individual components as well as the entire network.
- *Network Performance*. Test performance by measuring data transfer and connection signaling. This will allow the network manager to identify potential bottlenecks and optimize performance.
- *Fault Isolation*. Conduct fault isolation within network using various diagnostic tools. This is particularly important in a combat environment where redundancy is critical.
- *QOS*. Evaluation of QOS parameters such as peak cell rate, sustained cell rate and burst tolerance will allow the manager to determine how bandwidth is being used (i.e. which applications are most bandwidth intensive) and by which user.
- *Security and OAM* (Operations, Administration and Maintenance). [ALL]

For SML, network management may prove difficult since there is only one professor maintaining the system. If the parallel network approach were used, then network analysis and management of SML would be somewhat easier because the SML would incorporate only one networking technology as opposed to two in the internal ATM LAN approach. At the Department of the Navy (DON) level, ATM network analysis is conducted using the "Office Automation Software Test Suite" under the Information Technology (IT) Umbrella program "PC-LAN+" contract. This program tests and evaluates the "most current system software, hardware and performance using IT-21 compliant operating systems and application software" from major ATM vendors. [HUN] The results from this analysis have been valuable in identifying the best ATM technology available today.

2. Documentation

No network can operate efficiently without accurate documentation. For ATM networks, this is particularly true due to the complexity of virtual channels and private networks, where not only a detailed log of the physical connections is necessary, but the logical links as well. Without documentation, whenever any changes (both logical and physical) are made to the network, a loss of efficiency and perhaps security could occur. This is true even for small LAN's such as SML where the physical connections are few, but the potential to form many logical connections is great.

3. ATM Training in SML

Following several weeks of hands-on training with IAA, the authors who have a strong background in networks have only begun to understand the basics of ATM configuration and internetworking. In fact, even the technicians from IAA had to refer to the textbook and communicate closely with their vendors in order to implement ATM. It is highly recommended that any future system administrator for SML have extensive training in ATM in order to maintain, as well as educate users of the lab. Most ATM vendors provide classes and tutorials for learning basic ATM knowledge and operation of specific components.

4. ATM Security in SML

Financial transactions, government/military communications, and medical systems are all dependent upon the security of data transmitted over permanent and switched virtual circuits (P/SVC). The ATM Forum recently released phase 1 specifications for ATM security in February 1998 under version 1.0 of the ATM Security Framework (see Appendix B for latest list of Approved ATM Forum Specifications). This phase is still in the definition phase of ATM security and defines a "number of security services for the ATM user plane and control plane" as well as "mechanisms for carrying security-related messages and required security infrastructure mechanisms." [PEY] Specifically, this phase has addressed the following topics: Generic Security objectives, Generic threats, Functional Security requirements and Security Services. The

"Plane specific interpretation of functional security requirements," and the "Requirements for support services" will be addressed in phase 2 of this specification.

With respect to security in SML, all ATM alternatives discussed (i.e. Parallel, Internal) would be protected from intrusion due to their physical and logical isolation from the rest of the campus.

E. CHAPTER SUMMARY

This chapter provided a basic introduction to the issues surrounding ATM implementation in the SML such as determining network loads, data links and cabling. Various implementation approaches including Switched Fast Ethernet were addressed to better understand the advantages, disadvantages and complexity of implementing such a network. Highlighted are several examples of the specific hardware, and average costs required to implement ATM in SML. Additionally, basic network issues were addressed such as network analysis, management, documentation, training and security to emphasize their importance in operating an ATM network.

Of special note, it is important to mention that the current trend of network speeds and bandwidth are outpacing computer processing power, internal bus bandwidth and disk speeds. In other words, future bottlenecks will occur *at the desktop* where slower software and hardware is unable to match network speeds. It is the authors' position that an ATM or Switched Fast Ethernet upgrade to SML will greatly enhance network measurement research of these bottlenecks.

V. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSION

One of the many objectives that NPS has established for Information Technology Management (ITM) students is to provide them with the knowledge of Information Systems technology to include computer and telecommunications systems. In achieving this objective, we feel that practical experimentation with ATM should be a part of that education. As ATM is used increasingly in the local area network environment, graduates of the ITM curriculum could be involved in managing ATM networks. So, it is logical that NPS provides students with the opportunity to experiment with this promising technology as part of their education in ITM. Such education can only be obtained through the development of an ATM lab that will afford students the opportunity to gain practical experience with this technology. Classroom instruction alone cannot educate a student in the complexity of ATM. The ATM lab would permit students to acquire not only a fundamental understanding of ATM, but operational knowledge as well to better assist them in managing such networks. In addition, faculty would have a resource for conducting research on ATM and for obtaining hands-on experience that would enhance their teaching effectiveness in networks.

This thesis provided a general model for the implementation of ATM in a local area network utilizing the SML as an example. Our model was intended to be as general as possible so that it could be implemented in any laboratory that currently uses a LAN.

B. RECOMMENDATIONS

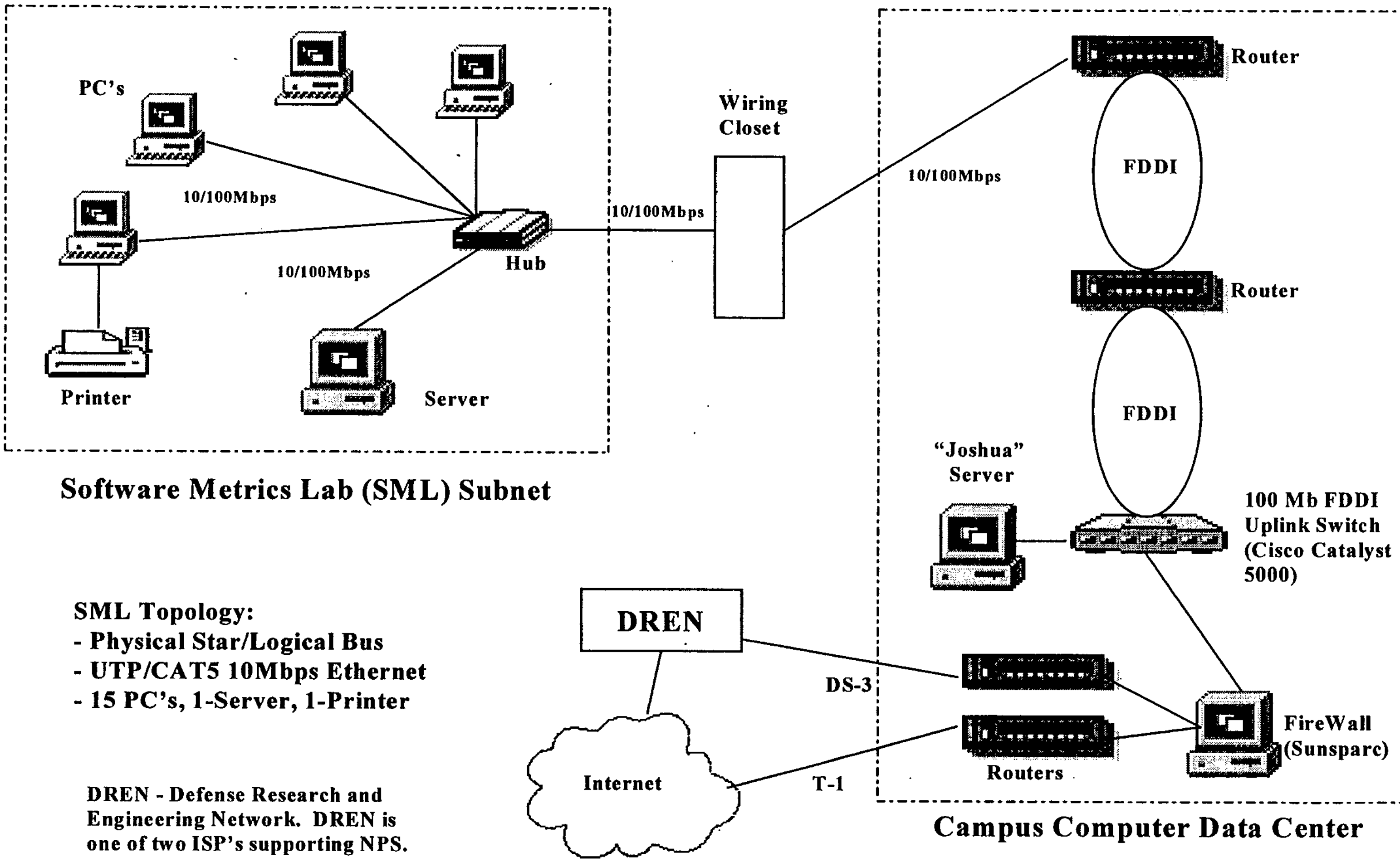
We presented three implementation alternatives that we felt NPS could employ that will provide students the exposure necessary to gain some degree of education about ATM. The ideal alternative, the parallel network, is the most highly recommended alternative, because it provides the opportunity to not only experiment with ATM in a local area environment, but a wide area environment as well. With the campus backbone being upgraded to ATM and the restriction of no user-controlled ATM devices connecting to the backbone, the parallel network is the only alternative that will enable students to experiment with ATM in both environments. Because this thesis did not discuss in depth the parallel network, the development and construction of this network would be a great subject for further research and a follow-on thesis.

The second implementation alternative, the Internal ATM LAN, would permit students and faculty to experiment with ATM in a local environment only. However, this alternative would require that two LANs be operated and maintained – the ATM LAN and the Ethernet LAN that connects to the backbone, thus requiring more support personnel. Despite the lack of connectivity with the ATM backbone , this alternative would still provide students with some understanding of ATM and the experience necessary to manage an ATM LAN. We only recommend this alternative if the parallel network is determined not to be feasible.

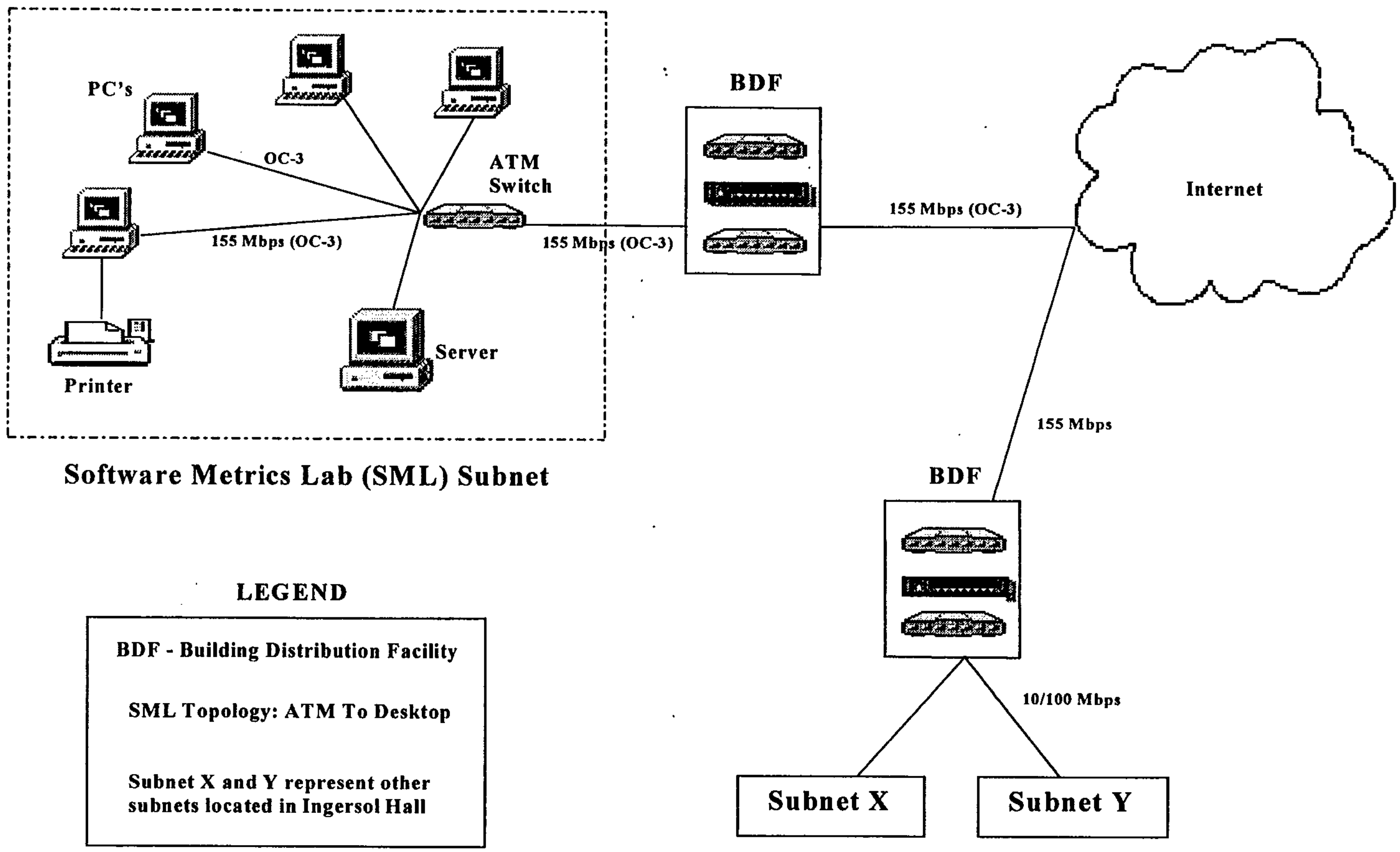
The last alternative, Switched Fast Ethernet with connectivity to the campus ATM backbone, limits student and faculty exposure to ATM. This alternative would not

provide direct contact and hands-on experience with ATM. However, this alternative would improve the performance of a lab that is currently using traditional Ethernet because it would replace it with Switched Fast Ethernet, a technology that eliminates the packet collisions of the former. With several military organizations already incorporating ATM into their network infrastructure, ITM students can expect to come in contact with this technology. We feel that it would be desirable for NPS, as part of their objective to educate students on networks, to develop an ATM lab.

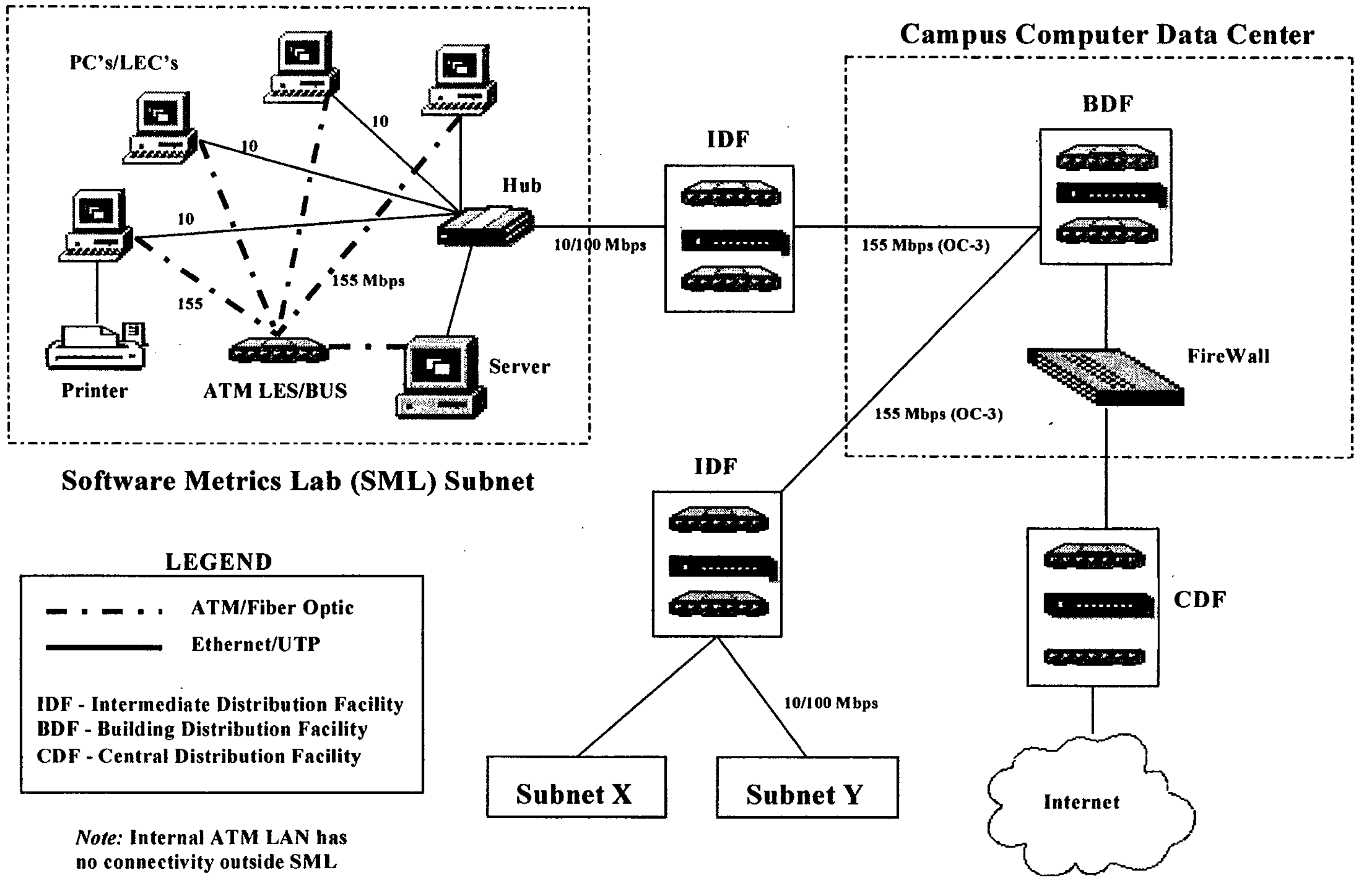
APPENDIX A-1. CURRENT SML CONNECTIVITY



APPENDIX A-2. PARALLEL ATM LAN



APPENDIX A-3. INTERNAL ATM LAN



APPENDIX B: CURRENT ATM FORUM SPECIFICATIONS

Approved Items as of August 1998

Below is a listing of all specifications completed and approved by the ATM Forum since its inception in 1991.

These documents may be found on the ftp server in several different formats. The document numbers listed here link to the .pdf version of the document where available.

Technical Working Group	Approved Specifications	Specification	Approved Date
B-ICI	B-ICI 1.0	af-bici-0013.000	Sep, 1993
	B-ICI 1.1	af-bici-0013.001	
	B-ICI 2.0 (delta spec to B-ICI 1.1)	af-bici-0013.002	Dec, 1995
	B-ICI 2.0 (integrated specification)	af-bici-0013.003	Dec, 1995
	B-ICI 2.0 Addendum or 2.1	af-bici-0068.000	Nov, 1996
Data Exchange Interface	Data Exchange Interface version 1.0	af-dxi-0014.000	Aug, 1993
ILMI (Integrated Local Mgmt. Interface)	ILMI 4.0	af-ilmi-0065.000	Sep, 1996
Lan Emulation/MPOA	LAN Emulation over ATM 1.0	af-lane-0021.000	Jan, 1995
	LAN Emulation Client Management Specification	af-lane-0038.000	Sep, 1995
	LANE 1.0 Addendum	af-lane-0050.000	Dec, 1995
	LANE Servers Management Spec v1.0	af-lane-0057.000	Mar, 1996
	LANE v2.0 LUNI Interface	af-lane-0084.000	July, 1997
	Multi-Protocol Over ATM Specification v1.0	af-mpoa-0087.000	July, 1997
	Multi-Protocol Over ATM Version 1.0 MIB	af-mpoa-0092.000	July, 1998
Network Management	Customer Network Management (CNM) for ATM Public Network Service	af-nm-0019.000	Oct, 1994
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	ATM User-Network Interface Specification V3.1	af-uni-0010.002	1994

APPENDIX C: GLOSSARY OF TERMS

AAL 1---Supports connection-oriented services that require constant bit rates and have isochronous-like timing and delay requirements. Example: circuit emulation service.

AAL 3/4---Intended for both connectionless and connection-oriented variable rate services. Originally two distinct layers, they have merged into this single AAL.

AAL 5---Supports connection-oriented variable bit rate data services such as the typical "bursty" data traffic found in today's LANs.

Asynchronous---Signals that are sourced from independent clocks. These signals generally have no relation to each other and have different frequencies and phase relationships.

ATM Adaptation Layer (AAL)---One of the three layers of the ATM protocol reference model. It performs Segmentation and Reassembly (SAR); translates higher-layer data into ATM cell payloads, and translates incoming cells into a format readable by the higher layers.

Available Bit Rate (ABR)---An ATM service type in which the ATM network makes a "best effort" to meet the transmitter's bandwidth requirements. ABR differs from other "best effort" service types by employing a congestion feedback mechanism that the ATM network uses to notify the transmitters that they should reduce their rate of data transmission until the congestion situation ceases. Thus, ABR does offer a qualitative guarantee that the transmitter's data should get to the intended receivers without experiencing unwanted cell loss. (see UBR)

Broadband ISDN (B-IDSN)---A set of services, capabilities, and interfaces supporting an integrated network and user interface at speeds greater than that of ISDN. The ITU-T initially decided to develop ATM for B-ISDN networks in 1988.

Broadcast and Unknown Server (BUS)---A LAN Emulation component that receives all broadcast and multicast MAC packets as well as MAC packets with an unknown ATM address and transmits these messages to every member of an emulated LAN.

Category 5 (CAT 5) Cable--- Data-grade UTP, capable of supporting transmission rates of up to 155 Mbps (but officially only up to 100 Mbps). The proposed CDDI (Copper Distributed Data Interface) networks and 100Base-X network architecture require such cable. [ENC]

Cell Loss Priority (CLP)---A one-bit descriptor found in ATM cell headers, indicating the relative importance of a cell. If set to 0, the cell should not be discarded. If set to 1, the cell can be discarded if necessary.

Congestion Collapse---A condition where re-transmission of frames are compounding an already congested ATM network or switch experiencing even small amounts of cell loss. Congestion collapse ultimately results in little or no traffic "goodput." ATM networks that do not employ ATM switches with either adequate and effective buffering mechanisms complimented with intelligent packet discard or ABR congestion feedback mechanisms frequently suffer congestion collapse.

Constant Bit Rate (CBR)---A data transmission that can be represented by a nonvarying, or continuous, stream of bits or cell payloads. Applications such as voice circuits generate CBR traffic patterns. CBR is an ATM service type in which the ATM network guarantees to meet the transmitter's bandwidth and Quality of Service (QoS) requirements. (see ABR, UBR, VBR)

Connection Admission Control (CAC)---The set of actions taken by the network during the connection setup phase in order to determine whether a connection's requested QoS can be accepted or should be rejected. (Generic) CAC is also used when routing a connection request through an ATM network (see PNNI).

Connection-Oriented---A type of communication in which a connection must be established between senders and receivers before data transmission can occur (contrast with TCP/IP connection-less).

Gigabit Ethernet---An extension of the 10 Mbps and 100 Mbps IEEE 802.3 Ethernet standards, with "a raw data bandwidth of 1000 Mbps," and fully compatible with existing Ethernet nodes. [GIG]

Goodput---Generally referring to the measurement of actual data successfully transmitted from the sender(s) to receiver(s). This is often a more useful measurement than the number of ATM cells per second throughput of an ATM switch if that switch is experiencing cell loss that results in many incomplete, and therefore unusable, frames arriving at the recipient.

Isochronous---Signals that are dependent on some uniform timing or carry their own timing information embedded as part of the signal.

IT-21---Set of standards endorsed by both U.S. Navy's Pacific and Atlantic Commander-in-Chiefs that will enable the Navy to shift from platform centric to network centric warfare. IT-21 is a concept for the "reprioritization of existing C4I programs of record focused on accelerating the transition to a PC-based tactical and support warfighting network."[CLE]

LAN Emulation (LANE)---Defines how an ATM network emulates enough of the MAC protocol of an existing IEEE LAN, specifically Ethernet and Token Ring. LAN Emulation allows existing higher-layer protocols and applications to be used transparently over an ATM network interconnecting Ethernet and Token Ring LANs. This subworking group in the ATM Forum is chaired by Cisco Systems.

LAN Emulation Client (LEC)---Software that resides in every LAN device attached to an ATM network, such as workstations, routers, and LAN switches. The LEC keeps learned address

translation information and establishes the direct connection necessary for communication with other devices over the ATM network.

LAN Emulation Configuration Server (LECS)---The LAN Emulation component that maintains configuration information about the ATM network and enables network administrators to control which physical LANs are combined to form VLANs.

LAN Emulation Server (LES)---The LAN Emulation component that provides MAC address-to-ATM address resolution services for LAN Emulation over an ATM network.

LAN Emulation User-to-Network Interface (L-UNI)---The ATM Forum standard for LAN Emulation on ATM networks; defines the interface between the LAN Emulation Client (LEC) and the LAN Emulation Server components. (see BUS, LES, LECS)

Media Access Control (MAC)---The lower half of the data-link layer that governs access to the available IEEE and ANSI LAN media.

Multiprotocol over ATM (MPOA)---A relatively new standardization effort in the ATM Forum that plans to specify how existing and future network-layer protocols such as IP, IPv6, Appletalk or IPX running over an ATM network with directly attached hosts, routers, and multilayer LAN switches will exploit the unique benefits of ATM. These benefits include quality of service (QoS) and direct connections between different VLANs. This subworking group in the ATM Forum is chaired by Cisco Systems.

Payload Type Identifier (PTI)---A 3-bit descriptor found in ATM cell headers, indicating what type of payload the cell contains. Payload types include user and management cells; one combination indicates that this cell is the last cell of an AAL5 frame.

Permanent Virtual Connection (PVC)---A logical (rather than physical) connection between endpoints established by an administrator that stays intact until manually torn down.

Point-to Multipoint---A unidirectional connection with one root endpoint and several leaves. See Point-to-Point.

Point-to-Point---A unidirectional or bidirectional connection with only two endpoints. See Point-to-Multipoint.

Private Network-to-Network Interface (NNI)---Also known as a Private Network-to-Node Interface. The interface between ATM switches or ATM switches and an entire switching system in a private network. The PNNI exchanges much more topological and complex quality of service (Q0S) routing information than the UNI.

Protocol Data Unit (PDU)---A unit of data consisting of control information and user data exchanged between peer layers.

Quality of Service (QoS)--- In ATM networks, a set of parameters for describing a transmission. These parameters include values such as allowable delay variation in cell transmission and allowable cell loss (in relation to total cells transmitted). The parameters apply to virtual channel connections (VCC) and virtual path connections (VPC), which specify paths between two entities. [ENC]

Relative Rate (RR) Mode---One of the congestion feedback modes allowed in the Available Bit Rate (ABR) service. In the Relative Rate Marking mode, switches can set a bit within either forward and backward Resource Management (RM) cells (or both) to indicate congestion. (see ABR)

Switched Virtual Connection (SVC)---A logical (not physical) connection between endpoints established by the ATM network on demand after receiving a connection request from the source/root. It is defined in the ATM Forum UNI specification and transmitted using the Q.2931 signaling protocols.

Switched Ethernet---An Ethernet switch is a device that can direct network traffic among several Ethernet networks. This type of switch has multiple ports to connect the subnetworks, and it generally has multiple processors to handle the traffic through the switch. Two types of Ethernet switches are common: store-and-forward, and a cross-point switch. In a sense, an Ethernet switch is just a superbridge for Ethernet networks. [ENC]

Synchronous---Signals that are sourced from the same timing reference and have the same frequency.

Traffic Policing---A mechanism used to detect and discard or modify cells/traffic that violate the traffic contract agreed to at connection setup. Although applicable to both public and private networks, traffic policing will most likely be used by public ATM service providers where tariffing can be based on guaranteed service.

Traffic Shaping---A mechanism used to shape or modify bursty traffic characteristics in order to match a desired traffic contract.

Unspecified Bit Rate (UBR)---An ATM service type in which the ATM network makes a "best effort" to meet the transmitter's bandwidth requirements; essentially a "send and pray" service like that available from today's networks.(see ABR)

Usage Parameter Control (UPC)---The set of actions taken by the network to monitor and control traffic. Its main purpose is to protect network resources from malicious as well as unintentional misbehavior, which may adversely affect the guaranteed service of other already established connections by detecting violations of negotiated traffic contract parameters and taking policing actions.

User-to Network Interface (UNI)---The ATM Forum specification that defines the interface that directly links a user's device to an ATM network through an ATM switch. (See PNNI)

Variable Bit Rate (VBR)---A data transmission that can be represented by irregular grouping of bits or cell payloads followed by unused bits or cell payloads. Most applications other than voice circuits generate VBR traffic patterns. VBR is an ATM service type and is divided into Real-Time VBR and non-Real-Time VBR, in which the ATM network guarantees to meet the transmitter's bandwidth and Quality of Service (QoS) requirements. (see ABR, UBR, CBR)

Virtual Channel Connection (VCC)---A concatenation of virtual channel links between to endpoints where higher-layer protocols are accessed.

Virtual Channel Identifier (VCI)---A connection-identifying value found in the header of each ATM connection cell.

Virtual Connection--- A connection between end users that has a defined route and endpoints. (see PVC, SVC).

Virtual Local Area Network (VLAN)---A collection of users or ports grouped together in secure, autonomous broadcast and multicast domain. Membership to a VLAN is not restricted by physical location and can be defined across multiple LAN switches and ATM devices in the enterprise. A VLAN in an ATM network is built upon an emulated LAN segment. (See LAN Emulation)

Virtual Path---An ATM network can be preconfigured with some number of virtual paths. Each virtual path can support many channels. Virtual paths can be used to construct end-to-end connections called VPCs.

Virtual Path Connection (VPC)---A concatenation of virtual path links between to points where the VCI values are either reassigned or terminated. Several different VCCs can be bundled into one VPC.

Virtual Path Identifier (VPI)---A connection identifying value found in the header of each ATM cell.

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